MISSION DEFINITION AND REQUIREMENTS AGREEMENT

for the

GRAVITY RECOVERY AND CLIMATE EXPERIMENT (GRACE) MISSION

UNIVERSITY OF TEXAS
CENTER FOR SPACE RESEARCH

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1.0 MISSION OVERVIEW

The primary goal of the GRACE mission is to obtain accurate global and high resolution models for both the static and the time variable components of the Earth's gravity field. This goal will be achieved by making accurate measurements of the inter-satellite range and range rate between two co-planar, low altitude polar orbiting satellites, using a microwave tracking system. In addition, each satellite will carry geodetic quality Global Positioning System (GPS) receivers and high accuracy accelerometers to enable accurate orbit determination, spatial registration of gravity data and the estimation of gravity field models.

The gravity field estimates obtained from data gathered by the GRACE mission will provide, with unprecedented accuracy, integral constraints on the global mass distribution and its temporal variations. In the oceanographic community, the knowledge of the static geoid, in conjunction with satellite altimeter data, will allow significant advances in the studies of oceanic heat flux, long term sea level change, upper oceanic heat content, and the absolute surface geostrophic ocean currents. Further, the estimates of time variations in the geoid obtained from GRACE, in conjunction with other in-situ data and geophysical models, will help the science community unravel complex processes in oceanography (e.g. deep ocean current changes and sea level rise), hydrology (e.g. large scale evapo-transpiration and soil moisture changes), glaciology (e.g. polar and Greenland ice sheet changes), and the solid Earth sciences.

This mission will be relevant to the goals of both MTPE EOS and the USGCRP. Implementation of the mission will be efficient and cost effective due to international collaboration. The GRACE Principal Investigator (PI), Dr. Byron Tapley of the University of Texas, Austin Center for Space Research (UTCSR), has established teaming arrangements with a Co-Principal Investigator, Prof. Dr. Christoph Reigber of the GeoForschungZentrum (GFZ), Germany; the Jet Propulsion Laboratory (JPL), Space Systems Loral (SS/L), the Dornier SatellitenSysteme, GmbH, the Applied Physics Laboratory (APL) at Johns Hopkins University, ONERA and the Langley Research Center (LaRC) to implement the GRACE mission. The PI will have overall responsibility for the total mission, including the instrument, spacecraft, ground system, mission planning and operations, data processing and analysis, and data distribution. Dr. Tapley will be supported by experienced management and engineering teams, which have established close and efficient working relationships. The Deutsche Forschungsanstalt fur Luft and Raumfahrt (DLR) and GFZ will work under an International Memorandum of Understanding (IMOU) between NASA and DARA (Germany). JPL and LaRC will perform under task orders from the Goddard Space Flight Center (GSFC) ESSP Project Office. SS/L, Dornier, APL and ONERA will perform under contract with JPL.

2.0 SCIENCE OBJECTIVES

2.1 Baseline Science Mission

Primary Objective:

The primary objective of the GRACE mission is to provide gravity models with accuracies that better existing global and high spatial resolution models of the Earth's gravity field by at least an order of magnitude, on a monthly basis, for a period of up to 5 years. The temporal sequence of gravity field estimates provide the mean (or static) gravity field, as well as a time history of its temporal variability. The scientific data products to be generated by GRACE including the line of sight inter-satellite tracking, GPS and accelerometer measurements, along with the ancillary data will be made available to the science community via the PODAAC at JPL in an EOS compatible format, shortly after validation for the entire life of the mission.

Secondary Objectives:

The secondary objectives are related to demonstrating the ability of the gravity measurements to discriminate time varying changes in the mass of the Earth's dynamic system, and to provide additional data to support investigation of the Earth's atmosphere. Specifically, these secondary objectives are:

- To demonstrate the ability to monitor the time varying effects due to sea level rise, water storage, ice change, and other geophysical phenomena, from a temporal sequence of gravity measurements.

- To advance atmospheric model studies by collecting several hundred globally distributed profiles of the ionosphere and the atmosphere every 24 hours, using GPS limb-sounding.

Baseline Science Objectives Summary

Accurate and high resolution estimates of the mean and time variable parts of the Earth gravity field will be obtained from satellite-to-satellite tracking data gathered from the GRACE mission. The mean value and time variations of the spherical harmonic coefficients of the Earth gravity field will be estimated using 12 to 24 day batches or cycles of these data. The accuracy of the estimated spherical harmonic coefficients can be expressed as the global root mean square (rms) error in the resulting area mean geoid height over a disk of a specified radius (or spatial resolution). Using 90 days of data, the nominal GRACE mission scenario will yield geoid height accuracies of better than 0.01

mm for spatial resolutions larger than 3000 km, increasing to 0.02 mm at 1000 km, 0.05 mm at 500 km and 5 mm at 100 km spatial resolutions

These nominal GRACE gravity field estimation errors can be further specified in terms of the primary science applications, as detailed in the original proposal. Table 1 presents the spatial and, where appropriate, temporal scales for the associated geoid accuracy requirements to support each scientific applications

Table 1 Baseline science objectives summary

APPLICATION	SPATIAL RESOLUTION	TIME SCALE	ACCURACY	COMMENTS
STATIC GRAVITY FIELD				
Oceanic Heat Flux	> 1000 km		> 40 percent improvements	
Ocean Currents	> 1000 km		< 1 mm geoid error	Improves to <0.1 mm for longest scales
Solid Earth Sciences	200 km		approx. 1 cm geoid error	
TIME VARIABLE GRAVITY FIELD				
Ocean Bottom Pressure	> 500 km	Seasonal	0.05 mBar pressure	90 day estimate
Deep Ocean Currents	> 500 km	Seasonal	1 cm/sec current velocity	90 day estimate
Sea Level Rise	> 700 km	Secular	0.1 mm/yr. water level	5 year estimate
Evapo - Transpiration	> 300 km	Seasonal	< 1 cm water equivalent	30 day estimate
Aquifer Depletion	> 300 km	Secular	1 - 2 mm/year water equivalent	5 year estimate
Greenland / Antarctic Ice		Secular	0.4 - 0.8 mm/yr. ice thickness	5 year estimate
- do -		Seasonal	3 - 10 mm ice thickness	1 year estimate

2.2 Minimum Science Mission

As a minimum goal for a successful mission, the GRACE measurements should support the requirement for at least an order of magnitude improvement in the marine geoid. This improvement will enhance dramatically the recovery of the general ocean circulation and ocean heat flux from satellite altimetry. This improvement is a current requirement of both the MTPE EOS and the World Ocean Circulation Experiment. To achieve minimum objectives of the GRACE mission, a static gravity field with a cumulative error of 5 mm root mean square over wavelengths 800 km and longer should be obtained. This will require separating the static and time varying signals during the observation interval. This goal should be readily attainable on the basis of one year of calibrated and validated data from GRACE's dual satellite microwave tracking system.

2.3 Science Data Products

2.3.1 Science Data Rights

There will be no proprietary science data rights for the mission. Science data will be made available to the public and the science community in an EOS compatible format after the appropriate science calibration and validation. The data and the associated higher level products will be made available in batches or cycles of 14 to 30 days each.

The Level-1 data products include the calibrated and verified satellite-to-satellite line of sight biased range and range rate, along with the GPS tracking data and precise ephemerides for the GRACE satellites. These data will be made available to the scientific community within 30 days of the last observation in each cycle.

The Level-2 data products include validated solutions for cycle averages of the Earth gravity field, in the form of coefficients of a spherical harmonic expansion and their time variations. These data products will be provided along with the equivalent 1x1 degree area mean geoid height and gravity anomalies on a global and regional basis. In addition, the one year average Earth gravity field model in the form of spherical harmonic coefficients as well as geoid height and gravity anomaly maps will be provided. The Level-2 products will be made available within 90 days of the last observation in each cycle.

The Level-3 data products contain higher level solutions targeted for geophysical quantities of interest. These include apparent changes in the 500 km disk averaged ocean bottom pressure as well as continental water storage over each cycle or averaging interval, as well as their longer term (annual and secular) variations. The Level-3 data products will be funded through a separate GRACE Mission Science Data Analysis Program and will be available on a schedule that is consistent with the selected investigation objectives.

2.3.2 Measurement Requirements

The Level 1 science measurement requirements are contained in Table 2. These requirements are consistent with successful accomplishment of the science objectives listed in paragraph 2.1 above.

Table 2 Level 1 Science Requirements

Science Investigation	Instrumentation	S/C	Ground Ops	Mission Design	Mission Ops.	Comments
Earth Gravity Field	μ-wave SST link, GPS Rcvr, Accelero-meter	2	Data Rate: 20 Mb/day	Inc 83°-90° Alt 450 km Life 5 yrs Sep 200 km	Orbit Maneuver Every 12 to 60 days	< 1μ/s SST < 1 nm/s^2 Accelero-meter
Atm Occult	GPS Rcvr.	1	Data Rate: 20-40 Mb/d			

2.3.3 Descope Options

A cascade of options for descoping the implementation and operations efforts (i.e. a Descope Plan) will be developed during Phase B. The Descope Plan will provide clarity in terms of how the primary scientific applications will be affected as each descope option is implemented. As a minimum, the Descope Plan will address any reductions in technical accuracy, mission lifetime and science data products. The descope options leading to the minimum science requirements described in Section 2.2 will be defined during the Phase B effort.

3.0 MISSION AND PROJECT REQUIREMENTS

3.1 Mission Cost and Budgetary Requirements

The GRACE mission will be undertaken on a "design-to-cost" basis. As proposed, the mission shall be accomplished with a cost to NASA of no more than . Failure to keep the estimated cost to complete the mission at any stage of the development of the mission may be cause for termination. Annual funding will be reflected in contracting vehicles between NASA GSFC and the implementing organizations. Adjustments within the overall "design-to-cost" funding level will be made between years through the normal contracting process. Approval will be sought from NASA for reductions in funding for “opportunity” activities.

3.2 Schedule

The Level-1 schedule milestones are listed below:

Project Requirements Review:	Apr 1998
Mission Design & Cost Review:	Dec 1998 (or sooner)
Critical Design Review	Mar 1999
Pre-Ship Review	Mar 2001
Internal Progress Reviews	(bi-annual)
Deliver Spacecraft to Launch Site	Jun 2001
Launch	Jul 2001
End of Mission	Jul 2006

3.3 Management System

The mission will establish an effective and efficient management system which will assure that the science objectives can be accomplished within the schedule and cost limitations. As a minimum the following management requirements will be met:

- The GRACE mission will be undertaken on a "design-to-cost" basis;
- All hardware and software will be verified through robust testing;
- Quality assurance program will be consistent, or exceed, standards set in ISO 9000;
- The Principal Investigator (PI) will exercise overall responsibility for the mission implementation and the leadership of the US Science Team;
- The PI will form and chair a Project Management Team (PMT) which will coordinate all program elements between organizations in both countries;

- The Co-PI will serve as a member of the PMT, lead the European Science Team, and provide management oversight of all German operations in support of this project;
- The Project Manager (PM), acting through JPL, will lead the satellite and system implementation effort, and be responsible for the mission and systems engineering team;
- DLR will be the lead agency for the mission operations effort of this project;
- GFZ will be the lead agency for the launch vehicle of this project

Any requisite modifications to these requirements for Phase C, D and E will be defined during Phase B.

3.3.1 Scheduling

A fully integrated scheduling system will be established and implemented during Phase B to manage all project elements. This system will include the development of network schedules and critical paths. A Level-1 baseline schedule will be developed during Phase B and approved by NASA.

3.3.2 Performance Metrics

A system to measure mission progress will be established and implemented during Phase B which is compatible with the scheduling and cost control systems.

3.3.3 Key Personnel

Changes in the key personnel, defined as the Principal Investigator and the Project Manager, will be subject to NASA approval. The key DARA and DLR personnel will be approved by the respective organizations.

3.3.4 Contract Deliverables

Major contracts which are developed as part of the mission will reflect the science nature of the investigation. As appropriate, deliverables will focus on the science products, and incentive plans will reflect the science deliveries. For this mission, primary emphasis is placed on cost and schedule.

3.3.5 Incentive Fee Plans

Implementation contracts will provide incentives to the contractor for both adherence to cost commitments and technical performance. Subcontracts from JPL for the GRACE Mission are currently in negotiations. Subcontractors include the Johns Hopkins Applied Physics Laboratory, Dornier SattelitenSysteme, Space Systems Loral and ONERA. Upon completion of contract negotiations, a discussion of fee pools and incentive plans will be added to this section.

3.4 Legal Requirements

The Project will abide by all necessary U.S. federal (including NASA), state and local laws and regulations.

3.5 New Facilities

There are no new project specific major facilities required for this mission

3.6 Descope Plan

The PI is responsible, directly and indirectly, through recommendations to the GSFC Mission Manager, for implementing the Descope Plan when it appears that the mission cannot meet its baseline science requirements. If a descope is necessary, the Descope Plan will describe how the Mission will meet the minimum science, budget and schedule requirements.

4.0 MISSION RESPONSIBILITIES

4.1 Principal Investigator and Science Team

The Principal Investigator (PI) will be responsible to NASA for achieving the objectives of the mission. The PI will establish and chair the Project Management Team (PMT) in order to coordinate the elements of the mission being executed by all the participants. The PI shall approve the designation of a single individual as Project Manager at JPL, and shall delegate to this individual the requisite responsibility and authority to manage and administer the effort to implement the GRACE mission. Decisions dealing with mission objectives will be made by the PI, in consultation with the PMT. The PI will also lead the scientific analysis team responsible for data analysis and distribution.

The Co-Principal Investigator (Co-PI), Prof. Dr. Christoph Reigber of GFZ, will be responsible to the PI for oversight of launch and on-orbit operations in fulfilling the mission requirements. He will also provide leadership of the European Science Team.

The Project Manager (PM) shall have delegated to him the requisite responsibility and authority to manage and administer the effort to implement the GRACE mission. This individual shall be the focal point of contact for GSFC. The PM shall ensure that all the objectives associated with the implementation effort are accomplished within schedule and cost constraints, and provide timely reporting of overall progress.

The tasks of the PMT, which consists of the PI, Co-PI, PM and other designated individuals, are to ensure that the program is guided in a responsive manner to maximize the science gains for the mission cost consistent with the constraints of ESSP.

The Science Team will be as described in the Science Requirements sub-section (Section 2.9) of the original proposal. The PI may change the composition of the science team to meet the objectives of the Mission, with notification of such changes to the ESSP Project Office. International participation will be consistent with the NASA/DARA Memorandum of Understanding.

4.2 Industrial Partners

Space System/Loral (SS/L) will perform the satellite system engineering, assembly, integration, and verification testing (AIVT).

The Dornier Satelliten Systeme, GmbH, an affiliate of Daimler-Benz Aerospace (DASA) will initiate the satellite system engineering process in an manner that optimizes the inheritance from Germany's CHAMP Mission, and is responsible for development of the thermal, structural and power systems of the satellites, and will also support launch integration on the COSMOS and launch operations.

4.3 Other Pre-selected Subcontractors

The Applied Physics Lab (APL) at Johns Hopkins University will develop the ultra stable oscillators (USO) to be used for the frequency standards in the SST tracking systems.

ONERA (France) will provide the accelerometers for the two satellites.

5.0 NASA RESPONSIBILITIES

The NASA HQ Code IY will provide support in the development of a Memorandum of Understanding (MOU) with the international partners on the GRACE mission. The GSFC ESSP Project Office will provide mission funding, contract administration and programmatic oversight for the GRACE mission. To implement the GRACE Mission, the ESSP Project Office will provide funds directly to three members of the GRACE Team - UTCSR, JPL and LaRC, as requested by the PI. Furthermore, the ESSP Project Office may provide other mission unique support, only as may be requested by the PI in writing and agreed upon by the ESSP Project Manager. In the event such support is requested, a portion of the PI's Mission Funds would be retained by the ESSP Project Resources Office, to be disbursed as requested by the PI.

6.0 REPORTING AND NASA REVIEWS

Reporting requirements and NASA reviews will be kept to a minimum while ensuring that NASA maintains an effective understanding of the progress of the development and execution of the mission. To this end, reports and supporting materials will be based on internal Project products and processes to the maximum extent practical. The details will be developed during Phase B between the PI, the Project Manager and the NASA Mission Manager.

NASA reviews will be conducted annually typically in conjunction with major project reviews by a team appointed by the ESSP Project Office to assess the progress of the mission and its readiness to proceed to the next phase. These reviews will assess technical, cost and schedule progress to verify that the project can be completed in accordance with the Level-1 requirements within the cost and schedule commitments. The results of these reviews will be reported to the Office of Mission to Planet Earth to confirm that the mission should be continued.